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THE ANALYSIS OF DYNAMIC PHENOMENA IN TECHNOLOGICAL SYSTEM AT MILLING CASE DETAILS

This article is intended to analyze the dynamic phenomena origin reasons in the process of milling as oscillatory cutting process and multimass elastically dissipative systems of the machine, reveal the origin conditions of pre-resonant and resonant phenomena in the system, and their mechanism and the energy level of performance and impact on the dynamic stability of the processing system.

Keywords: dynamic and resonant phenomena, milling thin-walled parts, cutting force

The paper investigates the dynamic oscillatory processes origin reasons in processing system, as an example – milling in the process of cutting and resilient, multi-mechanical system of the machine, their functional interdependence conditions, origin conditions of resonant phenomena in this case, their physics, energy level and the impact of such events on the quality of processing.

Objects and methods of research

The object of study in this paper is a manufacturing process of milling the thin-walled parts made of aluminum, and the subject of research is dynamic and resonant phenomena in technological system when milling the thin-walled parts made of aluminum.

Research methods are stability theory of elastic mechanical systems and their oscillations, experimental research of milling process, methods of vibration signal analysis, the scientific basis of such phenomena stabilization capability.

Setting objectives

It is known that the milling process is always accompanied by dynamic phenomena that affect the cutting process, the tool's stability and the quality of the surface to be processed. The main reason for the oscillations of the technological processing system is the unsteadiness of the cutting process [1-5].

The appearance of vibrations in the cutting process and their resonant phenomena in the processing system is a significant barrier for increasing the productive processing of parts on the machine and their quality. This problem is further complicated by the fact that it is difficult to predict, in each case, which of the parameters of the processing and to which side (reduction or increase) are needed to be adjusted to ensure the stability of the processing [6].

It is known that two types of oscillations are observed when tooling: forced and those that are stimulated first. Forced oscillations appear due to the periodicity of the action of the perturbing force of cutting. They can arise as a result of: the intermittent nature of the cutting process; wearout of a cutting tool; unevenness of the rolling of the workpiece for processing and its displacement during fixing; unbalance of machine components, parts and tools; defects in the mechanisms of the machine [2,3].

The most important thing is the determination of the influence of the dynamics of individual components of the technological processing system on the pre-resonant and resonant phenomena origin conditions, their mechanism and energy level, the effect and the impact on the dynamic stability of the technological processing system (TPS).

The given task can be solved by mathematical modeling of dynamic vibrational processes in the technological processing system during milling.

Results and discussion

The wearout of the tool also causes the error of processing the details because there is inconsistency of its actual size to the calculated size, which was taken when creating a control program for a CNC machine.

If the processing time of one part with the tool is significantly less than the time of its dimensional stability, the effect of the tool wearout can be taken into account by making a correction based on the results of the measurement of the processed parts. On the other hand, the wearout of the tool increases the cutting forces, resulting in the deformation of the TPS, as well as, respectively, the processing errors.

The appearance of inadmissible vibrations in the process of cutting from resonance phenomena is a significant obstacle for the productive milling of the workpiece on the machine tools. This problem is further complicated by the fact that it is difficult to predict in each case which of the parameters of the processing and to which side (reduction or increase) are needed to be adjusted to ensure the stability of the processing. Various methods of reducing the levels of acoustic vibration radiation of noise sources and vibration elimination are used to do this, such as: localizing acoustic vibration radiation propagation ways; injection of additional oscillations using antivibrators; improvement of organizational and preventive measures at work. But promising is the adaptive regulation of the parameters of the elastic system and the cutting modes for suppressing resonances.

When cutting, self-oscillation pathogen is an ambiguous quasi-periodic force of cutting and the presence of elastic deformations of the TPS. And the causes of the instability of the cutting force are the change of rejection Δt, the hardness of the material ΔHB, the frequency of the chip formation T_p, the friction of the tool and the part, as well as the influence of external factors from the engines of the machine tool, etc. In the presence of self-irritation in the system of contact "part-tool", small oscillations are amplified to some constant value with the amplitude, which makes an equilibrium between the energy supporting the oscillations and the energy of the scattering comes into play.

The quality of the process of mechanical processing (PMP) is significantly influenced by dynamic phenomena of different nature and intensity in the form of oscillatory processes of its elements that arise in an elastic TPS. If during milling on universal metal-cutting machines the pre-resonance phenomenon occurs and the worker can still track and take appropriate measures, then on CNC machines such a phenomenon inevitably leads to an emergency situation and even to a breakdown. Unfortunately, deep analysis in the technical literature in the field of the development of resonant phenomena in mechanical systems is not enough.

Origin conditions of dynamic phenomena

The origin condition of dynamic processes in TPS, as known, is variable in size and quasi-periodic in time dynamic component of cutting force $\Delta P_d(\tau)$, which arises from disturbing characteristics of the cutting process variable in time. Established [1] that the greatest impact on the value $\Delta P_d(\tau)$ in the milling causes a variation of the cut depth $\Delta t(\tau)$, where the main role is played by bias of the blank when it is being established and fixed in the adaptation of the machine and its manufacturing geometric errors. This causes a change in allowance and cutting force, which leads to the dynamics of cutting force $\Delta P_y(\tau)$ acting on the spindle speed per second ω_d.

However, there are some additional disturbing periodic cutting forces such as uneven width and depth of milling, frequency of cutting and exiting of each tooth of cutter, heterogeneity of the material, the frequency of the chip formation T_p, the frequency of the friction forces changes F_{Tp}, like friction-relaxation processes of friction in the contact zone of the tool with the workpiece and so on. Then the total variable force in the direction of the axis Y-Y, which affects the quality of processing the most, can be represented as (1,2,4) taking to account the temporary factors:

$$P_y(\tau) = P_{cp} + \Delta P_{dy}(\tau)\sin\omega_d\tau + \sum_{i=1}^{n} C_{pi}\cos(\omega_d\tau i + \varphi_i) \qquad (1)$$

where P_{cp} – the average value of the cutting force, determined by known dependence;

C_{pi} – force coefficients of variable additional elements of cutting forces of lower orders, in the fractions of the energy level from the main dynamic component of the cutting force in the direction of normal $\Delta P_{dy}(\tau)$, as their reduction in magnitude and number of them is n;

$\omega_d\tau$ – time period of change of the basic periodicity of the change $\Delta P_{dy}(\tau)$;

φ_i – phase shift of the vectors of additional dynamic forces of cutting relative to the Y axis, forming the entire other high-frequency spectrum of the oscillations of the cutting force $P_y(\tau)$;

i – their serial number by decreasing energy influence on the dynamics of cutting.

Such a dynamic mode of operation of the cutting process, depending on the processing time τ and the allowance $\Delta t(\tau)$, will be recorded as:

$$T_p \frac{d^2 P_y(\tau)}{d\tau^2} + P_y(\tau) = -K_p(\tau)Y \tag{2}$$

Y - the value of the elastic relative oscillation of the part and the cutting tool;

$K_p(\tau)$ – coefficient of rigidity of cutting, defined as:

$$K_p(\tau) = \frac{P_y(\tau)}{t(\tau)} \tag{3}$$

In processing, the cutting depth $t(\tau)$ periodically varies (± Δt), which also changes the cutting force, so $K_p(\tau)$ is also a variable; $K_p(\tau)$ - is the time of chip formation, as shown by the study, changes with the change of ω_d and determines higher spectrum of the oscillations frequencies of PMP.

Dynamic vibrational mode $P_y(\tau)$ causes periodic, elastic, relative movements of the part and tool to a value Y, which leads to the appearance of elastic oscillations of the elements of the TPS and the emergence of a secondary dynamic vibrational mode in this elastic-dissipative mechanical system in the form of a self-oscillatory process. It is described by the equation [5]:

$$M\frac{d^2Y}{d\tau^2} + H\frac{dY}{d\tau} + CY = f_{Tp}P_Y(\tau) \tag{4}$$

where ***M*** –the weight of the system; ***H*** - its dissipative-damping characteristics; ***C*** - its rigidity; f_{Tp} - coefficient of friction when cutting metal.

The functional dependence of the TPS dynamics in the form of a dynamic operator W_{YCC} as an elastic system of the machine, on its main indicators (4.5) will look:

$$W_{YCC} = f(M; H; C; P_y(\tau)) \tag{5}$$

From this it follows that the self-oscillatory in the TPS is disturbed and supported by a quasiperiodic change in the force of cutting $P_y(\tau)$ and at the same time largely determined by the dynamic constant characteristics of this system M, H and S.

Investigation of oscillatory dynamic modes of PMP and TPS, and their phase-frequency characteristics (PHC) allowed to draw the following conclusions:

1. PHC of PMO is largely determined by the spindle rotational speed ω_d and in the process of processing can vary in a wide range in the transition from semi-pulp to finishing processes.
2. In the case of machining, the tool wears out and stops, because of this T_p and f_{Tp} changes, and the PHC and PMO are gradually shifted to the low frequency region.
3. PHC TPS is largely determined by the dynamic constant of the elastic-dissipative system, such as M, H and C, which causes its certain inertia to change the PHC of the PMO at work.

Determination of the causes of resonant phenomena

The TPC itself is a multi-element system with its m_i, c_i i h_i, which have their own influence on the system and distort the dynamics of self-oscillations. All these elements of TPS at work depend on their FHC and their own limit of free frequency oscillation:

$$\omega_{oi} = \sqrt{\frac{C_i}{m_i}} \tag{6}$$

When changing the PHC of the machining process, there are always inevitable cases when the dynamic characteristics ω_{di} (1) of the cutting process can coincide by the frequency and phase with ω_{oi}, as $\omega_{di} \approx \omega_{oi}$, which leads to resonance in the processing system.

Consider the mechanics and physics of the occurrence of such a phenomenon during milling on the example of one of the elements of an elastic TPS. If such an element with mass m is brought out of equilibrium at a distance Y and let go, then it will start elastic oscillations and at the end of each turn there will be two forces acting on it:

• the force of inertia of motion, which is equal to Newton's second law (the second derivative of force for acceleration);

• the elastic force of the system cY.

By the principle of Dalamber at the end of the journey, the sum of the forces acting on such a body is equal to 0:

$$mY'' + cY = 0 \tag{7}$$

Transforming the equation we obtain:

$$Y'' + \frac{c}{m}Y = 0 \tag{8}$$

It is accepted to replace the ratio $\frac{c}{m}$ by the frequency of the subject self-vibration $\omega_0 = \sqrt{\frac{c}{m}}$.

As a result, we obtain the equation

$$Y'' + \omega_0^2 Y = 0 \tag{9}$$

When imposing disturbing quasi-periodic oscillating force $P_Y(\tau)$ (1) on such an element, in which the fundamental frequency of oscillation is ω_d , we obtain the equilibrium of forces by Dalamber at any time

$$P_y(\tau)\sin\omega_d\tau - cY - mY'' = 0 \tag{10}$$

or

$$mY'' + cY = P_y(\tau)\sin\omega_d\tau \tag{11}$$

The resulting equality is heterogeneous, since the right part is not zero. It can be solved in individual cases. Consider the case with the condition that the element with mass m is at the beginning of the coordinate movement Y_0 . Then, when disturbing it with frequency $\omega_d\tau$, we obtain the equations of motion of such a body:

$$Y = Y_0 \sin\omega_d\tau \tag{12}$$

Where Y_0 – represents the amplitude of forced oscillations and it is chosen from the condition of satisfaction of the equation (11). Twice differentiating (12) determine the acceleration of such oscillatory motion:

$$Y'' = -Y_0\omega_d^2 \sin\omega_d\tau \tag{13}$$

Substituting (12) and (13) in the expression (11) we obtain:

$$-mY_0\omega_d^2 \sin\omega_d\tau + cY_0 \sin\omega_d\tau = P_y(\tau)\sin\omega_d\tau \tag{14}$$

After the cuts and transformations in the end we have:

$$cY_0 - mY_0\omega_d^2 = P_y(\tau) \tag{15}$$

This allows us to find the amplitude Y_0 of such forced oscillations of elements of the elastic system of the TPC:

$$Y_0 = \frac{P_y(\tau)}{c - m\omega_d^2} \tag{16}$$

Replacing c and m through $\omega_0 = \sqrt{\frac{c}{m}}$, we find

$$Y_0 = \frac{P_y(\tau)}{c(1 - \frac{\omega_d^2}{\omega_0^2})} \tag{17}$$

From the obtained result it turns out that in such oscillations with disturbing frequency ω_d, their amplitude Y_0, when approaching ω_d to the frequency of internal oscillations ω_0 of the elastic system element, begins to increase rapidly and to be drawn into the resonance phenomenon. When there is a special case $\omega_{di} \approx \omega_{oi}$, then $Y \to \infty$. However, due to the presence of dissipative factors in the system, the amplitude of such oscillations has a certain limit. But the energy level of such oscillations is very high and leads to loss of dynamic stability of PMP and TPS.

We investigate such an energy level of the resonance. The kinetic energy of motion of such oscillations of an element with mass m is determined by the expression:

$$W_k = \frac{m\nu^2}{2} = \frac{m}{2}(\frac{dY_i}{d\tau})^2 \tag{18}$$

Analysis (17) and (18) shows that with constant c - elasticity, m - body mass and frequency ω_d amplitude of oscillations Y_i grows rapidly. Consequently, in order to satisfy equality, it grows with the same speed and speed of displacement ν, with the quadratic dependence and the kinetic energy of such a resonance phenomenon can grow to large values, which can lead to loss of quality of PMP and the reliability of the TPC.

Conclusions

When milling, there always are variable characteristics that disturb elastic TPS and force of cutting, as a number of triggers of dynamic oscillation processes. In addition to the main dynamic vector $P_d(\tau)$ acting with frequency ω_d, in $P_y(\tau)$ there are triggers of the dynamics of the cutting forces of small orders (1), which have a whole spectrum of system disturbing frequencies ω_{di} of higher order. In addition, the processing system itself is multivariate, multi-elemental and elastic with its own m_i, that have different frequencies of its own oscillations ω_{0i}. When cutting tool is blunt, the entire frequency range of the cutting force $P_y(\tau)$ is shifted to the low frequency region.

All of these factors represent a high probability of occurrence of resonant phenomena in machining with coincidence of ω_{di} and ω_{0i}.

So the development and implementation of automatic control systems represents an actual problem of improving the quality of processing.

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